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R-parity Violating Radiative Photino Decay in Supersymmetric Models

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It has been shown that unless the tri-linear R-parity violating coupling λ_{i33} ($i = 1, 2$) is small enough ($\lambda_{i33} < 10^{-2}$ for MSSM and 10^{-3} for GMSB model), the partial decay width of photino decaying into 'photon + $\nu_{e,\mu}$ ', both in supergravity motivated (MSSM) and gauge mediated (GMSB) supersymmetric models are larger than the partial decay width of photino decaying into 'photon + goldstino' in R-parity conserving GMSB model including one loop supersymmetric QED correction.

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Confirmation of neutrino oscillation by Superkamiokande experiment [1] leads to the conclusion of non-zero neutrino mass. In Minimal Supersymmetric version of Standard Model either Supergravity motivated (we refer it as MSSM) [2] or Gauge mediated (which we refer as GMSB) [3], this feature of non-zero neutrino mass is realized through R- parity violation in the theory. Supersymmetric models with R parity violation opens up a plethora of new signals or can mimic the signals of R- parity conserving models. In the present work, we have computed such loop induced photino decays $\tilde{\gamma} \rightarrow \gamma\nu_e$, $\tilde{\gamma} \rightarrow \gamma\nu_\mu$ via R- parity violation. The qualitative nature of both these processes are same and the quantitative difference arises due to the difference in respective R-parity violating couplings. Keeping this feature in view, in the following, we represent both the decays as $\tilde{\gamma} \rightarrow \gamma\nu_i$ (where $i = e, \mu$) and the decay amplitude of both the processes will be evaluated just by replacing the respective R-parity violating coupling. Furthermore, we have neglected the decay process $\tilde{\gamma} \rightarrow \gamma\nu_\tau$ as it is much suppressed compared to the other two processes. This is precisely because $\tilde{\gamma} \rightarrow \gamma\nu_i$ decays involve heaviest τ lepton in the loop whereas $\tilde{\gamma} \rightarrow \gamma\nu_\tau$ decay involves e and μ leptons. The decay $\tilde{\gamma} \rightarrow \gamma\nu_i$ mimics the signal of $\tilde{\gamma} \rightarrow \gamma\tilde{G}$ in R-parity conserving GMSB model where $\tilde{\gamma}$ is the Next to Lightest Supersymmetric Particle (NLSP). Both these decay process, $\tilde{\gamma} \rightarrow \gamma\nu_i$ and $\tilde{\gamma} \rightarrow \gamma\tilde{G}$, give rise to the same final state " $\gamma + \cancel{E}$ ". We have also considered one loop supersymmetric QED correction of the decay $\tilde{\gamma} \rightarrow \gamma\tilde{G}$. There is not much enhancement in the partial decay width due to this correction and we find that the partial decay width of $\tilde{\gamma} \rightarrow \gamma\nu_i$ decay process is larger than the $\tilde{\gamma} \rightarrow \gamma\tilde{G}$ decay, unless the trilinear λ_{i33} (where $i = 1, 2$) coupling is too small. Fur-

thermore, if R parity is violated , there will be possible three body photino decay ($\tilde{\gamma} \rightarrow fff$) and it has been shown [5] that non-observation of such signal put a stringent constraint on the trilinear R-parity violating coupling $< 10^{-5}$, through the comparison between the partial decay width of $\tilde{\gamma} \rightarrow \gamma\tilde{G}$ with $\tilde{\gamma} \rightarrow fff$. A recent analysis [6] in this path has been done through the inclusion of bi-linear R-parity violating term and it has been shown that the branching ratio of $\tilde{\chi}_1^0 \rightarrow \nu\gamma$ decay can have a maximum value of about 5 - 10%. In the present work, we find that the tri-linear R-parity violating λ_{i33} coupling alone give rise to a larger partial decay width of the decay process $\tilde{\gamma} \rightarrow \gamma\nu_i$ compared to the one loop supersymmetric QED corrected decay process $\tilde{\gamma} \rightarrow \gamma\tilde{G}$, unless the value of λ_{i33} is too low. Thus, if R-parity is violated, ambiguity arises to interpret the observed signal " $\gamma + \cancel{E}$ " or " $\gamma\gamma + \cancel{E}$ " etc. [7],[8] as a low energy signature of R-parity conserving GMSB model in an unambiguous way. Some other complementary signal in collider experiment should be needed which when taken into account with the "photon + missing energy" signal could lead us to confirm any of these models. Before going into the details, we like to mention the followings: First, although, in general, lightest neutralino $\tilde{\chi}_1^0$ is an admixture of the neutral gauginos and neutral Higgsinos, however, the present state of knowledge leads to the fact that the $\tilde{\gamma}$ component is dominated over the largest region of allowed parameter space [9]. The relevant mixing factor arises due to general consideration of $\tilde{\chi}_1^0$ structure will modify equally all the decays discussed in the present work. Second, we discard any photino-lepton-slepton off diagonal coupling in the present work.

To compute one loop supersymmetric QED correction to the decay of

$\tilde{\gamma} \rightarrow \gamma \tilde{G}$ in R-parity conserving GMSB model, we consider the following goldstino-lepton-slepton interaction Lagrangian [10]

$$L = -ie_{gL}\sqrt{2}[\bar{e}_L\tilde{e}_L\tilde{G} + \tilde{\bar{G}}\tilde{e}_L^\star e_L] + ie_{gR}\sqrt{2}[\bar{e}_R\tilde{e}_R\tilde{G} + \tilde{\bar{G}}\tilde{e}_R^\star e_R] \quad (1)$$

where

$$e_{gL} = \frac{m_{\tilde{e}_L}^2 - m_e^2}{d}, e_{gR} = \frac{m_{\tilde{e}_R}^2 - m_e^2}{d}, d = \sqrt{\frac{3}{4\pi}}M_{Susy}^2 \quad (2)$$

In the above expressions $m_{\tilde{e}_L}$, $m_{\tilde{e}_R}$ are the masses of the left-slepton and right-slepton and M_{Susy} is the supersymmetry breaking scale parametrized in terms of parameter d . In GMSB model, masses of left-slepton and right-slepton are wide apart primarily due to their different representation under SU(2) gauge group and since $m_{\tilde{e}_L} \gg m_{\tilde{e}_R}$ we have discarded the contribution due to $m_{\tilde{e}_L}$. Furthermore, we ignored any non-degeneracy in right-slepton masses and $m_{\tilde{e}_R}$ represents mass of the right-selectron. The one loop supersymmetric QED corrected diagrams of the decay $\tilde{\gamma}(q) \rightarrow \gamma(p_2)\tilde{G}(p_1)$ is generated due to slepton-lepton particles in the loop. The squark-quark induced loop diagrams are neglected since $m_{\tilde{q}} \gg m_{\tilde{l}}$. Neglecting lepton masses as well compared to selectron mass, we obtain the following matrix element

$$-iM_{loop} = i\left(\frac{2e^2}{16d\pi^2}\right)m_{\tilde{e}_R}^2 A \bar{u}(p_1)\gamma^\rho u(q)\epsilon_\rho^\star \quad (3)$$

where

$$A = -\frac{3}{2}\ln(1+p-2p^2) + \frac{p}{18} + \frac{143}{60}p^2 \quad (4)$$

and $p = \frac{m_{\tilde{\gamma}}^2}{m_{\tilde{e}_R}^2}$ where $m_{\tilde{\gamma}}$ is the mass of the photino. It is to be noted that as $p \rightarrow 0$, still there is a non-zero contribution to the loop correction due to the presence of the second term in the right-hand side of Eqn.(4), which

shows non-decoupling effect of the above process. This is basically due to the proportionality of the coupling of the Goldstino-lepton-slepton term in the lagrangian with the slepton mass squared.

The relevant part of the Lagrangian required to calculate tree level $\tilde{\gamma}(q) \rightarrow \gamma(p_2)\tilde{G}(p_1)$ is given by [11]

$$L = \frac{1}{2d} \partial_\mu \tilde{\gamma} \gamma^\mu [\gamma^\nu, \gamma^\rho] \tilde{G} \partial_\nu A_\rho + h.c. \quad (5)$$

and the tree level matrix element comes out as

$$-iM_{Tree} = i \frac{3m_{\tilde{\gamma}}^2}{2d} \bar{u}(p_1) \gamma^\rho u(q) \epsilon_\rho^*(p_2) \quad (6)$$

The total matrix element M_{total} (= tree level + one loop) of the decay process $\tilde{\gamma} \rightarrow \gamma \tilde{G}$ can be written as

$$M_{total} = M_{tree}(1 + \Delta) = \frac{3m_{\tilde{\gamma}}^2}{2d} \left(1 + \frac{e^2}{12\pi^2} \frac{m_{\tilde{e}_R}^2}{m_{\tilde{\gamma}}^2} A\right) \bar{u}(p_1) \gamma^\rho u(q) \epsilon_\rho^*(p_2) \quad (7)$$

where $\Delta = \frac{M_{loop}}{M_{tree}}$ is the enhancement factor. For a typical mass value of $m_{\tilde{\gamma}} = 80$ GeV and $m_{\tilde{e}_R} = 100$ GeV which are allowed in GMSB model, we found the enhancement in M_{total} due to one loop correction is $\Delta \sim 6 \times 10^{-3}$ for three generations of leptons. For higher values of photino and right-selectron masses the correction becomes more and more insignificant. Thus, we find that the enhancement due to the one loop supersymmetric QED correction of the decay $\tilde{\gamma} \rightarrow \gamma \tilde{G}$ is insignificant compared to its tree level decay mode.

Next, we consider the one loop decay of $\tilde{\gamma} \rightarrow \gamma \nu_i$ in MSSM induced by the tri-linear R-parity violating λ_{i33} coupling. The relevant diagrams are obtained by replacing goldstino field of the previous process by the ν_i field with R parity violating λ_{i33} coupling, however, unlike the previous case, there

is a chirality flip in the internal lepton(s) line(s) due to Yukawa type nature of the R-parity violating interactions, and therefore, we cannot neglect lepton mass in this case. We have considered heaviest τ lepton contribution only and as we have considered photino-lepton-slepton flavour diagonal coupling, the other particle circulating in the loop is $\tilde{\tau}_R$. Furthermore, we have ignored any non-degeneracy between $m_{\tilde{\tau}_L}$ and $m_{\tilde{\tau}_R}$ and we have also ignored λ' coupling induced $d - \tilde{d}$ interactions by considering $m_{\tilde{d}} \gg m_{\tilde{\tau}_R}$.

We consider the following R-parity violating trilinear interaction,

$$L_{\mathbb{R}_p} = \frac{\lambda_{i33}}{2} [\tilde{\tau}_L \nu_{iL} \bar{\tau}_R + (\tilde{\tau}_R)^* (\nu_{iL})^c \tau_L] + h.c. \quad (8)$$

The squared matrix element of the process $\tilde{\gamma} \rightarrow \gamma \nu_i$ comes out as

$$|M|^2_{MSSM} = 16Q^2 [2A^2 - B_1^2 (A_1 + C)(B + C) - 2AB_1(B + C)] \quad (9)$$

where

$$Q = \left(\frac{\lambda_{i33}\alpha}{4\sqrt{2}\pi} \right) \left(\frac{m_\tau}{m_{\tilde{\tau}}} \right) m_{\tilde{\gamma}}^2 \quad (10)$$

$$A = \frac{t}{t-1} \ln t - \ln t - 1 \quad (11)$$

$$A_1 = \frac{2}{1-t} (t \ln t + 1 - t) - 1 + \frac{2}{(1-t)^2} \left(\frac{t^2}{4} - \frac{1}{4} - \frac{t^2}{2} \ln t \right) \quad (12)$$

$$B = \frac{t}{1-t} \ln t + 1 \quad (13)$$

$$B_1 = \frac{3}{t-1} \quad (14)$$

$$C = \frac{1}{(1-t)^2} \left[t \left(1 - \frac{t}{2} \right) \ln t + \left(t - \frac{1}{4} \right) - \frac{3t^2}{4} \right] \quad (15)$$

and $t = \frac{m_{\tilde{\tau}}^2}{m_{\tilde{\tau}}^2}$. Neglecting higher powers of t , we obtain a simpler expression for $|M|^2_{MSSM}$ as

$$|M|^2_{MSSM} = 16Q^2[2(1 + \ln t)^2 + \frac{9}{2}\ln t + \frac{45}{16}] \quad (16)$$

The partial decay width comes out as

$$\Gamma_{\mathcal{R}_p}^{MSSM} = \frac{1}{16\pi} |M|^2_{MSSM} \frac{1}{m_{\tilde{\gamma}}}. \quad (17)$$

The partial decay width $\Gamma(\tilde{\gamma} \rightarrow \gamma \tilde{G})$ in R-parity conserving GMSB model at the tree level is given by [12]

$$\Gamma(\tilde{\gamma} \rightarrow \gamma \tilde{G})^{GMSB} = \frac{m_{\tilde{\gamma}}^5}{6M_{Susy}^4} \quad (18)$$

and for the previous choice of photino mass and $M = 150$ TeV, the partial decay width comes out as $\Gamma(\tilde{\gamma} \rightarrow \gamma \tilde{G})^{GMSB} \sim 0.10 \times 10^{-11}$ whereas $\Gamma_{\mathcal{R}_p}^{MSSM} \sim 0.17 \times 10^{-7} \times \lambda_{i33}^2$ for $m_{\tilde{\tau}} = 200$ GeV, $m_{\tilde{\gamma}} = 100$ GeV. Thus, unless λ_{i33} is very small ($< 10^{-2}$), $\Gamma(\tilde{\gamma} \rightarrow \gamma \nu_i)_{\mathcal{R}_p}^{MSSM} > \Gamma(\tilde{\gamma} \rightarrow \gamma \tilde{G})^{GMSB}$. Such a value of λ_{i33} is well within the present upper bounds: $\lambda_{233} < 0.09(\frac{m_{\tilde{\tau}}}{100\text{GeV}})$, $\lambda_{133} < 0.24(\frac{m_{\tilde{\tau}}}{100\text{GeV}})$ [13].

Similar result is also obtained in case of GMSB model including R-parity violation. The squared matrix element in this case is given by

$$|M|^2_{GMSB} = 4(\frac{\lambda_{i33}\alpha}{4\sqrt{2}\pi})^2 t_1 [2(1 + \ln t_1)^2 + \frac{9}{2}\ln t_1 + \frac{45}{16}] \frac{m_{\tilde{\gamma}}^4}{m_{\tilde{\tau}_R}^2} \quad (19)$$

$$+ \text{terms containing } m_{\tilde{\tau}_L} \quad (20)$$

where $t_1 = \frac{m_{\tilde{\tau}}^2}{m_{\tilde{\tau}_R}^2}$ and as before we have neglected higher powers of t_1 . We can also neglect left-slepton contribution in the above expression since $m_{\tilde{\tau}_L} \gg m_{\tilde{\tau}_R}$ in GMSB model. The partial decay width comes out as

$$\Gamma_{\mathcal{R}_p}^{GMSB} = \frac{1}{16\pi} |M|^2_{GMSB} \frac{1}{m_{\tilde{\gamma}}}. \quad (21)$$

For a typical choice of model parameters, $m_{\tilde{\gamma}} = 80$ GeV , $m_{\tilde{\tau}_R} = 100$ GeV we obtain, $\Gamma_{\tilde{\mu}_p}^{GMSB} = 0.21 \times 10^{-7} \times \lambda_{i33}^2$. Hence , as before , unless $\lambda_{i33} < 10^{-3}$, the partial decay width of R-parity violating photino decay ($\tilde{\gamma} \rightarrow \gamma \nu_i$) in GMSB model is larger than the R- parity conserving photino decay ($\tilde{\gamma} \rightarrow \gamma \tilde{G}$) mode.

In summary, we have calculated partial decay width of one loop radiative photino decay ($\tilde{\gamma} \rightarrow \gamma \nu_i$) (where $i = e, \mu$) both in MSSM as well as GMSB models due to tri-linear R-parity violating interactions. We have also computed one loop supersymmetric QED corrected amplitude of the decay process $\tilde{\gamma} \rightarrow \gamma \tilde{G}$ in R-parity conserving GMSB model. We found that for a typical choice of model parameters the enhancement due to this correction , $\Delta(=\frac{M_{loop}}{M_{tree}})$ is of the order of 6×10^{-3} for three generations of leptons. We have compared the one loop QED corrected partial decay width of the decay $\tilde{\gamma} \rightarrow \gamma \tilde{G}$ with the R-parity violating $\tilde{\gamma} \rightarrow \gamma \nu_i$ decay for both MSSM and GMSB models and we found that unless the tri-linear R-parity violating λ_{i33} (where $i = 1, 2$) coupling is small enough ($\lambda_{i33} < 10^{-2}$ for MSSM and 10^{-3} for GMSB model), the partial decay width of this loop induced process is larger than the photino decay $\tilde{\gamma} \rightarrow \gamma \tilde{G}$ in R-parity conserving GMSB model. The upshot of this analysis leads to a crucial position to interpret the collider signal "photon + missing energy" as a signature of R-parity conserving GMSB model in an unambiguous way.

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